CERN SPS/88-53(AMS)
LHC Note No. 86

An Experimental Insertion for the LHC with a Very Low β^* at the Interaction Point.

Beat T. Leemann and Walter Scandale

Abstract

A solution of a high luminosity, very low β insertion for the Cern LHC is presented as an alternate injection insertion at IR1. This is an immediate extension of previous lattice design work for LHC (ref.[1]). The dynamic and chromatic properties of this insertion are reported.The effects on the dynamic aperture caused by the implementation of this high - luminosity insertion are studied and compared to previous short term LHC tracking results (ref.[2]).

Prévessin - October 19, 1988

1. Introduction

The experimental insertion proposed is consistent with the specifications of the LHC lattice, discussed in ref. [1]. The reduced value of β^* results from the location of the inner triplets of quadrupoles, which is substantially closer to the interaction point than in the previously described IR - optics. Thus, a higher luminosity is obtained in pp - collisions at the expense of a reduced free space available for an experimental device, dedicated to the observation of large transverse momentum reactions.

Values for β^* as low as a quarter of a meter are obtained, using quadrupole gradients not exceeding 250 T/m, with the focusing triplets located 6 m apart from the crossing point ($L^*= 6$ m).The chromatic abberations and the restrictions of the dynamic aperture in presence of the random component of the multipole moments in dipoles and quadrupoles are evaluated.

2. Layout of the insertion and its performance.

The layout proposed is derived from that of the injection insertion IR1 in ref. [1]. The free space around the crosssing point has been reduced from ± 10 m t o ± 6 m . The inner triplet $\{Q_1, Q_2, Q_3\}$ is slightly larger where as the outer triplet $\{Q_4, Q_5, Q_6\}$ is more compact. The separating dipole doublet and the dispersion suppressor region with its four quadrupoles Q_7, Q_8, Q_9 and Q_{10} are unchanged. A free space of 117.7 m is now available between the separating doublet and the outer triplet to accomodate the injection devices. By tuning the gradients of the 10 quadrupoles Q_1 through Q_{10}, the standard matching conditions of ref. [1] are obeyed and the values of β^* can be varied from 0.24 m to 2.2 m . The peak values of β at the edges of the quadrupoles in the inner and outer triplets are for the collision optics 4843 m and 508 m, respectively, 534 m and 252 m , respectively for the injection optics. The orbit functions for β^*=0.25 m and 2.2 m are shown in figures 1 and 2. The gradient required in the insertion quadrupoles are below 250 T/m, when β^* varies from 2.2 m to 0.28 m . A further reduction of β^* to 0.24 m is possible by increasing the gradient of Q_7 in the dispersion suppressor to 253.2 T/m . A solution to avoid this minor inconvenience will be studied later.

3. Chromatic behaviour

The chromatic behaviour of the LHC has been studied for the injection insertion IR1 as presented above, with β^*= 0.25 m , the other experimental insertions tuned for collision optics (normally IR5 and IR7 have β^*= 0.5 m) and the even insertions and IR3 have the usual high β configuration. The sextupolar gradient K_2 required to cancel the horizontal and vertical chromaticities are 0.0567 m^{-3} and 0.11048 m^{-3}, respectively. The momentum dependent tune shifts are plotted in figures 3 and 4 .

The variations of the optical parameters over the momentum range of $\delta = \pm 1.8 \times 10^{-4}$, which corresponds to ± 4 times the rms momentum spread in the bunch at full energy, are :

$$\Delta\nu_h = 1.2 \times 10^{-4} \qquad \Delta\beta_{h,max} = 31 \text{ m}$$
$$\Delta\nu_v = 1.4 \times 10^{-4} \qquad \Delta\beta_{v,max} = 21 \text{ m}.$$

The differences are tolerable and of the same order of magnitude as that of the nominal lattice [1].

4. Tracking

The dynamic aperture of the lattice described in ref. [1] has been investigated for various IR-optics configurations by short term tracking and these results are reported in ref. [2]. To study the effect on the dynamic aperture, when the present high luminosity, very low β - insertion is implemented in IR1, the same tracking requirements and conditions as in ref.[2] are applied. These are summarized in the following paragraph.

The dynamic aperture is determined based on a particle's survival of 400 revolutions using the tracking code "FASTRAC" (ref.[3]). The initial conditions are chosen along the axis of equal emittances in the transverse planes : $\varepsilon_x = \varepsilon_y = \varepsilon$. The maximum initial amplitudes $a = (\varepsilon)^{1/2}$, leading to stable motion over 400 revolutions are the quoted aperture figures. The LHC requires apertures of 0.61 mm at injection (450 Gev) and 0.19 mm at collision (8 TeV), respectively (cf. ref.[2]) . Only the random part of the magnetic imperfections in the dipole magnets and in the quadrupole magnets are included up to 9^{th} order. The values used are listed in table 1. No binning or sorting of the dipole magnets is assumed.

Table 1: Random Errors in Units of 10^{-4} at $r_0 = 10^{-2}$ m. [# of poles = 2 * (order + 1)]

order	dipole		quadrupole		IR-triplet	
k	$\sigma_{b,k}$	$\sigma_{a,k}$	$\sigma_{b,k}$	$\sigma_{a,k}$	$\sigma_{b,k}$	$\sigma_{a,k}$
0	0.0	0.0	0.0	0.0	0.0	0.0
1	0.0	0.0	0.0	0.0	0.0	0.0
2	1.5	0.5	2.28	2.10	0.1	0.1
3	0.15	0.2	0.34	0.72	0.1	0.1
4	0.2	0.07	0.16	0.17	0.1	0.1
5	0.0	0.0	0.12	0.06	0.1	0.1
6	0.02	0.04	0.02	0.02	0.022	0.022
7	0.0	0.0	0.0	0.0	0.016	0.016
8	0.05	0.002	0.007	0.006	0.013	0.013
9	0.0	0.0	0.005	0.004	0.009	0.009

5. Tracking Results : On-momentum

The tracking results for various optics along the tuning path from injection to 4 possible collision scenarios are summarized in table 2. Again, as in ref. [2], the even numbered insertions are held at a constant β^* of 6.5 m, while for IR "3" and IR "7" β^* is kept at the injection value of 4 m. Columns 1 and 2 of table 2 list the values for the extrema of the β - function in IR1 and IR5, respectively. Column 3 shows the natural chromaticities of the bare lattices. Finally, the average on-momentum dynamic apertures (based on 5 different random number seeds) for 3 error configurations are given in columns 4 - 6 : a_0 is the aperture of the bare, chromaticity corrected lattice, a_1 is the aperture when all random dipole and quadrupole imperfections , except for those of the inner IR triplets, are included, and a_2 is the value obtained when the inner IR triplet errors are included also.

Table 2 : On-momentum tracking results for the present very low β insertion in IR1.

IR1 β^* β_{max}	IR5 β^* β_{max}	$-\xi_{nat}$	a_0 [mm]	a_1 [mm]	a_2 [mm]
2.2 558	4.0 521	110.5	2.063 ±.038	1.100 ±.114	0.853 ±.051
0.5 2419	1.0 2054	136.7	1.697 ±.028	1.068 ±.099	0.354 ±.014
0.3 4020	1.0 2054	149.5	1.473 ±.019	1.045 ±.105	0.261 ±.017
0.25 4819	1.0 2054	156.0	1.473 ±.019	1.015 ±.111	0.230 ±.009
0.25 4819	0.5 4085	168.9	1.375 ±.019	1.016 ±.100	0.221 ±.013
0.24 5019	0.5 4085	170.5	1.329 ±.021	1.021 ±.103	0.215 ±.015

The results for the high luminosity optics have to be compared to those for the 2-fold symmetry case in ref. [2], which for convenience are listed in table 3.

Table 3 : Previous tracking result for 2-fold symmetry lattice (cf. ref.[2])

$\beta^*_{IR1/5}$ [m]	β_{max} [m]	$-\xi_{nat}$	a_0 [mm]	a_1 [mm]	a_2 [mm]
0.5	4084	157	1.472 ±.028	0.980 ±.152	0.230 ±.015

6. Tracking Results : Off-momentum

The off-momentum behaviour was studied for the collision optics case with $\beta^*_{IR1} = 0.24$ m and $\beta^*_{IR5} = 0.5$ m . The average values based on 5 random number seeds are listed in table 4. The overall shape of the chromatic aperture is given by the bare lattice, while the maximum stable amplitude depends on the strength of the errors included. For convenience the results for the 2-fold symmetry case of ref. [2] are listed in table 5.

Table 4 : Chromatic aperture for very high luminosity collision optics.

δ [10^{-3}]	-1.4	-0.7	0	0.7	1.4
$< a_{dyn} >$ [mm]	0.241 ±.028	0.227 ±.007	0.216 ±.006	0.206 ±.019	0.195 ±.013

Table 5 : Chromatic aperture for collision optics of 2-fold symmetry lattice (cf. ref.[2])

δ [10^{-3}]	-1.4	-0.7	0	0.7	1.4
$< a_{dyn} >$ [mm]	0.248 ±.009	0.248 ±.023	0.230 ±.015	0.225 ±.020	0.217 ±.006

7. Conclusions

The implementation of the proposed very low β-insertion in the LHC lattice poses no problems as far as the dynamic aperture (based on 400 turns tracked !) is concerned. Comparing the present results with the previous ones (refs.[1] & [2]) it is obvious that the differences are statistically insignificant. Thus, under the made assumptions, that the systematic errors are taken care of by a corrector scheme and neither closed orbit distortions nor the synchro-betatron coupling cause substantial aperture losses, the dynamic apertures obtained by short term tracking of the realistic LHC lattices including the specified random errors are satisfactory.

8. References

[1] W. Scandale CERN SPS / 88-6 (AMS), LHC Note No. 68

[2] B.T. Leemann and W. Scandale, Proc. European Acc. Conf. ,June 1988

[3] B.T. Leemann and E. Forest,SSC-133,June 1987